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REPORT NO T6/83

**DEVELOPMENT AND ASSESSMENT OF THE
MONARK CYCLE ERGOMETER
FOR ANAEROBIC MUSCULAR EXERCISE**

**US ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts**

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instantaneous application of resistance is presented. In addition, the methods used to measure pedal revolutions and to calibrate the ergometer, and the analysis of the forces acting on the flywheel are described. Finally, a description of the procedure used in the performance of the Wingate test and a summary of the actual data output are presented. ,

FOREWORD

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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TECHNICAL REPORT

NO. T6/83

**DEVELOPMENT AND ASSESSMENT OF THE MONARK
CYCLE ERGOMETER FOR ANAEROBIC MUSCULAR EXERCISE**

by

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Abstract

This report describes the system developed by this Institute to measure anaerobic power production using the protocol developed at the Wingate Institute in Israel. This test consists of 30 seconds of maximal cycling (or cranking) exercise against a resistance determined according to the body weight of the subject. The system consists of a modified Monark cycle ergometer, a universal counter to monitor flywheel revolutions, and a desktop computer for timing, control, and data processing. The modification of the ergometer for the instantaneous application of resistance is presented. In addition, the methods used to measure pedal revolutions and to calibrate the ergometer, and the analysis of the forces acting on the flywheel are described. Finally, a description of the procedure used in the performance of the Wingate test and a summary of the actual data output are presented.

Introduction:

The role of the oxygen transport system in the assessment of physical performance has been widely studied. Indeed, the measurement of maximal oxygen uptake is generally accepted as a reliable and valid indicator of the capacity to generate muscular power through oxidative metabolism. Relatively little information is available, however, as to the contribution of anaerobic metabolism in muscular exercise although it is generally accepted that exercise of high intensity and short duration is primarily dependent upon anaerobic processes for energy release.

The relative lack of information on anaerobic capacity is largely due to methodological considerations. There appear to be no tests of anaerobic power or capacity available which have gained the popularity equivalent to the determination of maximal oxygen uptake as a measure of aerobic capacity. Although attempts have been made to develop laboratory tests considered to reflect anaerobic characteristics which are accurate, reliable and valid, most have not been accepted by more than isolated research groups. Examples of such tests include the stair-climb test of Margaria (1), the 40-sec run test of Matsudo (2), an exhaustive run on the treadmill (3), and the one-minute cycle ergometer test of Szogy (4). That such tests are predominantly "anaerobic" in nature has been inferred from power outputs, calculations of oxygen deficits or debts, and blood lactate concentrations. Furthermore, little data exist as to the reliability, validity and specificity of these tests.

During the past few years a project has been carried out by researchers (5, 6) at the Wingate Institute in Israel on the development of a simple cycle ergometer test of anaerobic power and/or capacity. The use of the Wingate Test (WT) for evaluating the capacity for short-term, exhaustive exercise has been reported by a growing number of laboratories (7, 8, 9, 10). The WT consists of 30

sec of exhaustive cycling (or cranking) exercise against a resistance determined according to the body weight of the subject. It has been found to be reliable (6) and a valid predictor of sprint running (11). Of the energy sources required for its performance, approximately 80% has been established to be anaerobic (12).

Our laboratory has been interested in the measurement of anaerobic power since it is believed to be an important component in the overall physical fitness of military personnel. A list of typical anaerobic activities would include sprinting up a steep incline, walking or running with a heavy load (e.g., weapons and ammunition), and heavy, repetitive lifting. The daily activity schedule of a combat soldier, therefore, involves numerous bouts of high-intensity anaerobic physical exercise. The WT as a measure of one's capacity for this component of fitness, offers the advantages of being simple, short, and requiring little equipment such that it could be easily performed in the field laboratory environment.

The objectives of this report are to describe, (1) modifications of the Monark cycle ergometer that allow for the instantaneous application of resistance and the means used to measure pedal revolutions, (2) the methods used to calibrate the cycle ergometer, and (3) the procedure used in performing the WT.

Modification of the Monark Cycle Ergometer

The system used in the performance of the WT is comprised of three components: a modified Monark cycle ergometer whose description follows, a Hewlett Packard 5328A Universal Counter to monitor flywheel revolutions, and a Hewlett Packard 85 Desktop Computer used for timing, control, and data collection and storage during the test period, and the processing and outputting of results immediately after the test. The modified cycle ergometer is shown in Figure 1. The weighted pendulum on the standard Monark cycle ergometer

(Model #858) has been replaced by an apparatus which enables a known resistance to be immediately applied to the flywheel (Fig. 2). The mechanism consists of a 15 in lever arm (Fig. 2, A) whose weight is counter balanced (Fig. 2, B). The lever arm is notched every 1/2 in between the 4th in and 15th in, measured from the lever arm's axis of rotation, to ensure firm and accurate seating of the weight (Fig. 2, C). One of four weights (1/2 lb, 1 lb, 2 lb, 4 lb) is attached at a calculated location on the lever arm to obtain the desired resistance on the flywheel. The band (Fig 2. D) is used to apply resistance to the flywheel. It is attached to a hook which is fixed to the lever arm 3 in from the lever arm's axis of rotation, travels over a pulley (Fig 2, E) located above the lever arm apparatus, around the flywheel and is anchored below the lever arm apparatus (Fig 2, F). The pulley allows the force to be applied tangential to the lever arm and minimizes losses due to friction.

Immediately below the lever arm a switch assembly (Fig. 2, G) is fixed to the cycle frame. The switch is used to control the onset of the test period. The measurement of flywheel revolutions during the test period is done using four circular, center mounted magnets (Fig. 3, A) and a coil and diode (Fig. 3, B). The latter are connected in series with the output cable (Fig. 3, C), while the magnets are fixed to equidistant locations around one face of the flywheel. When the weighted lever arm is lowered to a horizontal position the band applies resistance to the flywheel and at the same time closes the switch. When the switch is closed the universal counter counts the pulses induced on the coil by each passing magnet.

Precision (timing, resolution)

The timing of the WT is controlled by the computer. The start of the test is triggered by the first magnet passing the coil after the switch has been closed. During the test the computer reads the output of the universal counter at the

end of each second of the test. The data are displayed on the computer's CRT and stored. The test period is terminated by the computer after 30.00 sec.

The flywheel revolves 3.71 times per pedal revolution which results in 14.84 magnets passing the coil per pedal revolution ($3.71 \text{ rev} \times 4 \text{ mag/rev}$). Therefore, the resolution of this system is 0.067 revolutions.

To determine whether the universal counter is accurately reflecting the number of pedal revolutions during a WT the system's output is periodically verified. The ergometer is pedalled at 30 RPM (.5 rev/sec), 60 RPM (1 rev/sec) and 120 RPM (2 rev/sec) in time to a metronome, each for a 30 sec period. The computer output is then checked to confirm that the output accurately reflects the known pedal rates.

Force Analysis

The forces (F_1 and F_2) acting on the flywheel resulting from the weight (w) on the lever arm and rotation of the flywheel are depicted in Figure 4.

The resistance (force, kg) applied to the flywheel is determined by calculating the sum of the moments (ΣM) about the lever arm pivot point; F_2 is subtracted from F_1 and divided by 2.2 (conversion to kg). F_2 is calculated using equations 1 thru 3:

$$aF_2 - (a + b) w = 0 \quad (1)$$

$$F_2 = \frac{(a + b) w}{a} \quad (2)$$

$$F_2 = w(1 + \frac{b}{a}) \quad (3)$$

where: $a = 3"$, distance from lever arm axis to band attachment
 $b =$ distance (in) from band attachment to weight position
 $w =$ weight (lb) fixed to lever arm

F_1 is measured directly with a 200 lb capacity BLH force transducer (Model U2M 1) which is attached to the ergometer at position F, Figure 2 and displayed with a BLH transducer indicator (Model 450A).

Figure 5 depicts the relationship between force development (F_1 - F_2) and the varying rotational rates of the flywheel (RPM). As shown, the resistance applied to the flywheel is not significantly changed by varying the RPM.

An empirical method (E) of calculating the force on the flywheel uses the following equation:

$$\text{Force (kg)} = (\text{lever arm position (in)} \times w(\text{lb}) \times 2/3) / 2.2 \quad (4)$$

A comparison of the force (kg) calculated using the two methods is presented in the following data (Table 1).

TABLE 1
Comparison of forces (kg) calculated by the ΣM
and empirical (E) method

Position of w on lever arm (in)	60 RPM				120 RPM			
	1 lb		2 lb		1 lb		2 lb	
	ΣM	E	ΣM	E	ΣM	E	ΣM	E
4	1.1	1.2	---	---	0.9	1.2	---	---
6	1.8	1.8	3.8	3.6	1.8	1.8	3.8	3.6
8	2.6	2.4	4.9	4.8	2.7	2.4	4.9	4.8
10	3.4	3.0	5.9	6.0	3.4	3.0	6.1	6.0
12	4.1	3.6	7.8	7.3	4.1	3.6	7.3	7.3
14	4.6	4.2	---	---	4.8	4.2	---	---

The data suggest no difference between the two ways of obtaining the force applied to the flywheel. Therefore it is suggested that since the empirical method is simpler to apply, it be used for daily application and the ΣM be used periodically to determine if there has been any significant change in the relationship of F_2 and F_1 due to a change in the coefficient of friction.

Calculation of Position of Weight on Lever Arm

The resistance applied to the flywheel is selected with the intention of enabling the subject to generate the highest 30 second power output possible. Bar-Or (5) found that 0.075 kg/kg body weight (BW) elicited the desired power output for lower body testing. For the upper body test a resistance of 0.050 kg/kg BW was determined to elicit the highest 30 sec power output. The desired resistance is achieved by placing a weight at a calculated distance on the lever arm. A 2 lb weight is generally used for tests of the lower body and a 1 lb weight is used for the upper body. The following formula (derived from formula 4) is used to calculate the position of the weight on the lever arm to generate the appropriate resistance:

$$\text{Position of } w \text{ (in)} = \text{Resistance (kg)} \times \text{BW (kg)} \times A \times 2.2 \quad (5)$$

where: Resistance = 0.075 kg for lower body
0.050 kg for upper body

A = 3/2 for 1 lb weight
3/4 for 2 lb weight
3/8 for 4 lb weight

Calculation of Power Output

The formula used to calculate the power output as a result of performing the WT is as follows:

$$\text{Power (Watts)} = \text{Force} \times 6m \times \text{Pedal Revolutions/sec} \times 60 \text{ sec}/6.12 \quad (6)$$

where: Force (kg) is calculated using equation (4)

6 m = distance flywheel travels per pedal revolution (3.71×1.617 m)

Pedal rev/sec derived from universal counter

6.12 = conversion from kg • m/min to watts

WT Procedure

Before each WT, subjects warm up for 2 - 4 minutes. They pedal at 60 RPM against a resistance of 1.5-2.5 kg, interspersing 2-3 "sprints" of 4-8 sec duration. The seat height of the ergometer is adjusted to each subject and toe clips are used to stabilize the subject's feet on the pedals. The subject is instructed to remain seated throughout the test. After entering initial data into the computer (body weight, w applied to lever arm, distance of w on lever arm) the subject is instructed to attain a pedal rate of about 120 RPM with no resistance applied to the flywheel. When the subject reaches this pedal rate he/she is instructed to pedal as rapidly as possible after the command "Ready, Go". This enables the subject to overcome the inertial resistance of the flywheel. When a maximal pedal rate is reached (within 2 sec), the lever arm is immediately lowered applying resistance to the flywheel and closing the switch. As a result the computer is triggered to start timing the test and begin data collection. The subject is strongly encouraged throughout the test to maintain a maximal pedal rate. At the end of 30 sec, the lever arm is lifted and the subject is told to relax. The subject then pedals at an arbitrary pedal rate with no resistance applied to the flywheel until he/she has sufficiently recovered.

Upon completion of the WT the mean power, peak power and power decrease of the test are calculated (expressed in watts) by the computer. The mean power is the average mechanical power output generated during the test period. The peak power is the highest power output during any 5 sec period. The power decrease is the difference between the peak power and the lowest 5 sec power output divided by the time elapsed between the two measurements. Along with these parameters a summary of the test is output by the computer (Fig 6). This summary consists of a listing of the cumulative revolutions updated in 5 sec intervals, the number of pedal rotations during each 5 sec period of the test and

the total power output (watts) during each 5 sec period of the test. Following the listing is a record of the actual resistance applied to the flywheel during the test (kg/kg body weight), the force the subject was pedalling against (kg), the mean power, peak power and power decrease during the test. The test is graphically represented by plotting the total power generated during each 5 sec period of time.

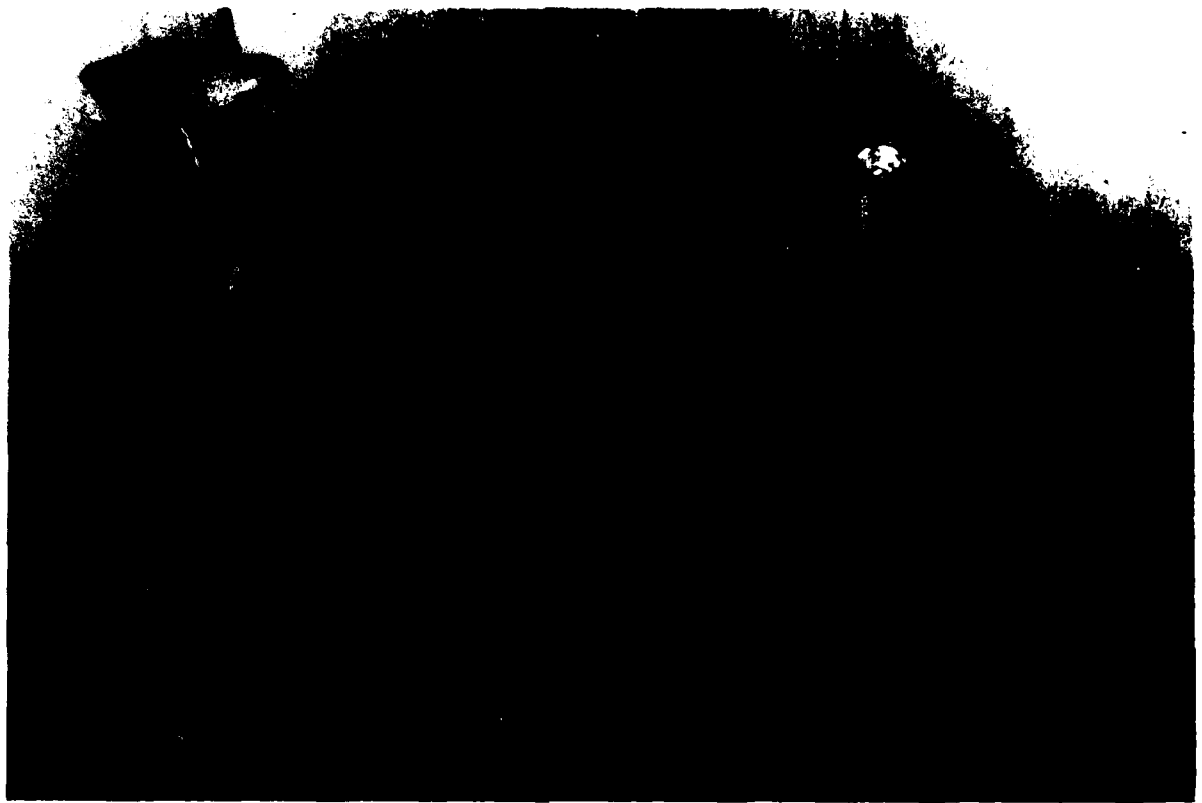


Figure 1. Modified Cycle Ergometer



Figure 2. Apparatus for Applying Resistance
to the Flywheel



Figure 3. Magnet (A), Coil (B), and Output Cable (C)
for Counting Flywheel Revolutions

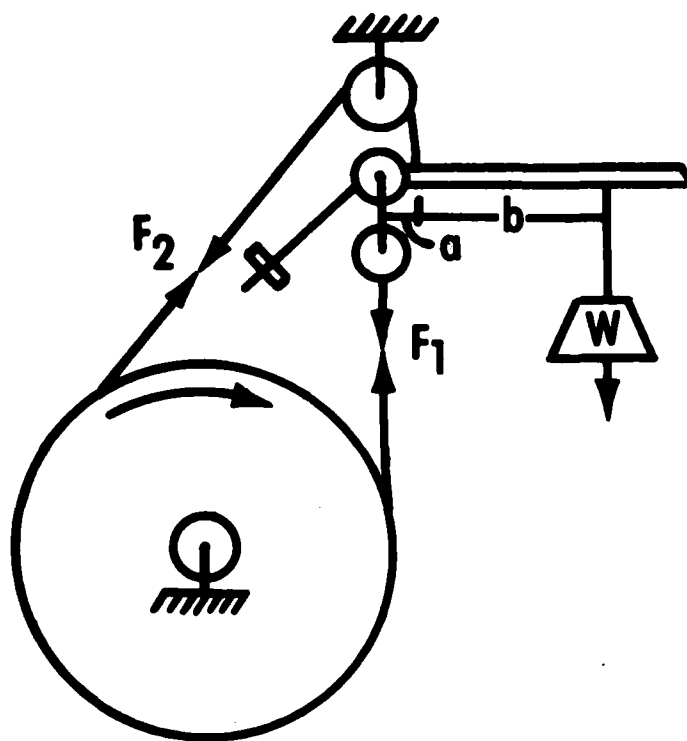


Figure 4. Diagram of Forces During Flywheel Revolutions

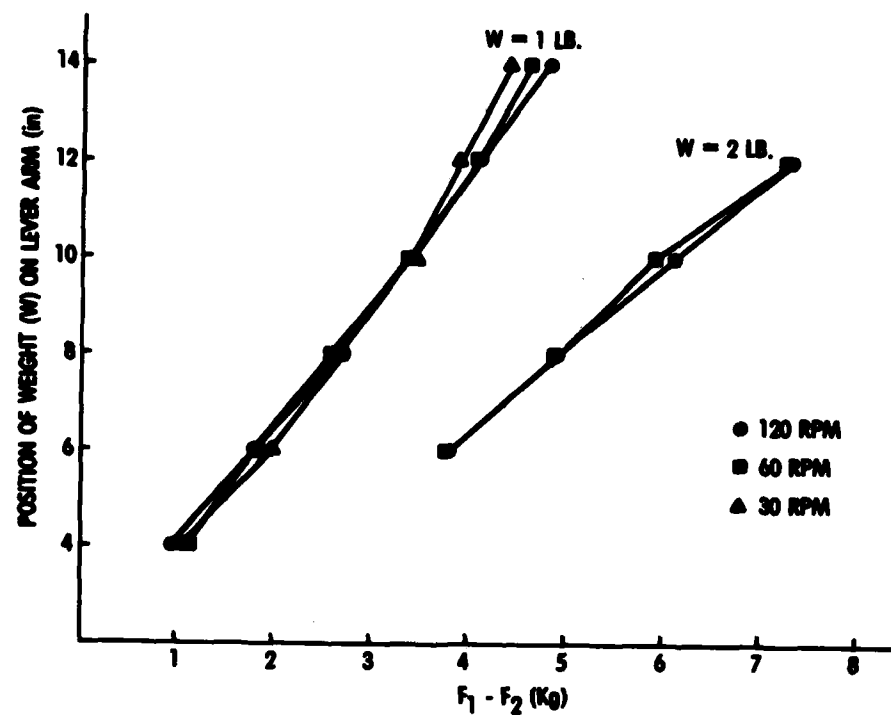


Figure 5. Relationship Between Force Development and Varying Rotational Rates of the Flywheel

SUBJECT NUMBER 8216

TIME (SEC)	CUM. REV.	REV./ 5 SEC	WATTS
5	12.8	12.8	775.1
10	23.8	11.0	669.0
15	33.4	9.6	579.3
20	41.9	8.5	518.1
25	49.6	7.7	465.0
30	56.5	6.9	420.2

RESISTANCE .073
FORCE (KG) 5.2
AVG POWER 571.4
PEAK POWER 775.1
POWER DEC 14.2
HEART RATE 196

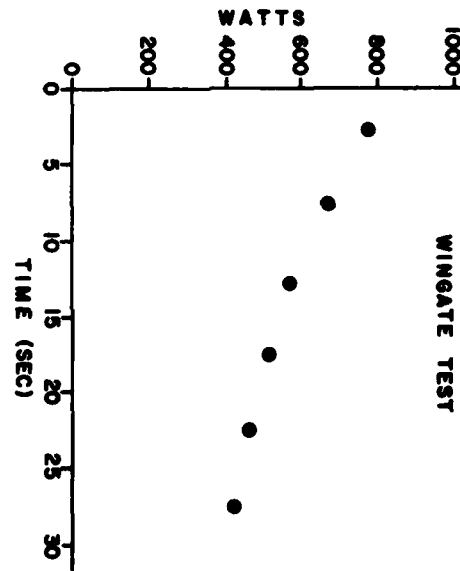


Figure 6. Summary of WT

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